LFull title:

How does land management contribute to the resilience of Mediterranean forests and rangelands? A participatory assessment

Short title:

PARTICIPATORY ASSESSMENT OF RESILIENCE IN MEDITERRANEAN ECOSYSTEMS

Authors:

Jucker Riva Matteo[1,2,*], Baeza Jaime[3], Bautista Susana[4], Christoforou Michalakis[5], Daliakopoulos Ioannis N.[6], Hadjimitsis Diofantos[5], Keizer Jan Jacob[7], Liniger Hanspeter[1,2], Quaranta Giovanni[8], Ribeiro Cristina[7], Salvia Rosanna[8], Tsanis Ioannis K[6]., Urgeghe Anna M. [4], Valdecantos Alejandro[3], Schwilch Gudrun[1]

[1]Centre for Development and Environment, University of Bern, Switzerland

[2] Institute of Integrative Geography, University of Bern, Switzerland

[3] Mediterranean Centre for Environmental Studies (Foundation CEAM), Spain

[4] Department of Ecology and IMEM, University of Alicante, Spain

[5] Department of Civil Engineering and Geomatics, Cyprus University of Technology, Cyprus

[6] School of Environmental Engineering, Technical University of Crete, Greece

[7] Centre for Environmental and Marine Studies, Dept. of Environment and Planning, University of Aveiro, Portugal

[8] Department of Mathematics, Computer Science and Economics, University of Basilicata, Italy

* Corresponding author: University of Bern, Centre for Development and Environment (CDE), Hallerstrasse 10, 3012 Bern (Switzerland). Phone: +41 31 631 88 22, matteo.jucker@cde.unibe.ch;

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1002/ldr.3104

1. Abstract

In Mediterranean forests and rangelands, the supply of important ecosystem services can decrease or cease as a consequence of disturbances and climatic oscillations. Land managers can sometimes prevent or mitigate the negative effects of disturbances through appropriate land management choices. In this study, we assess the contribution of land management practices (LMPs) to the resilience of eight Mediterranean forests and rangelands to multiple disturbances. The study uses a transdisciplinary approach, involving scientists, land managers, and local administrators. Data about disturbances, ecosystem services, the role of LMPs, and the resistance of LMPs to disturbances are combined using a semi-quantitative index, and analysed to evaluate how the LMPs implemented are suited to the disturbances affecting each study site. Our results indicate that the practices analysed are particularly effective in improving resilience of ecosystems against wildfires and torrential rainfalls. However, droughts are more difficult to address, and the examined practices were heavily affected by their occurrence. Tree planting appears to be highly affected by disturbances. Practices that selectively reduce the amount of vegetation appear to be beneficial in fostering recovery of ecosystems. Our assessment also suggests that it is particularly difficult to increase resilience to droughts and fires simultaneously. Practices that aimed to mitigate the impact of land use did not always prove valuable in terms of resilience. Finally, study sites that included efforts to address disturbances in their management objectives also displayed practices making the biggest contribution to resilience.

2. Introduction

Dry Mediterranean ecosystems have a long history of exposure to climatic oscillations and land use changes (Alados *et al.*, 2011; Blondel, 2006; Daliakopoulos *et al.*, 2017; Zdruli, 2014). However, land degradation caused by disturbances affects the supply of ecosystem services, sometimes irreversibly (Baeza *et al.*, 2007; Bowman *et al.*, 2016; Mayor *et al.*, 2016; Santana *et al.*, 2014), with negative consequences for the well-being of land users and for the functioning of the ecosystem at larger scale. For example, low Mediterranean woodlands can shift to shrublands after repeated or intense fires (Baeza *et al.*, 2007; Lozano *et al.*, 2012; Pausas *et al.*, 2008). Droughts can trigger shrub encroachment in grass-dominated pastures, changing not only the economic value of the land but also the water cycle at a larger scale (Caldeira *et al.*, 2015; Folke *et al.*, 2004).

Our study aims at evaluating the contribution of land management practices (LMPs) to the resilience of six Mediterranean rangelands and forests affected by disturbances, using as input information gathered through a knowledge co-creation process. Within the context of this study we define resilience as the ability of a land management system to remain productive and valuable, according to land users' evaluations, by withstanding disturbances or recovering from them. Results are analysed to evaluate whether the combination of LMPs implemented in each study site is appropriate to cope with the disturbances affecting each ecosystem, and to obtain a general indication on how different types of practices can contribute to the resilience of natural and semi-natural ecosystems.

Resilience (Holling, 1973), defined as the capacity of a system to withstand or recover from disturbances, is an important feature of ecosystems and a highly debated topic in recent ecological and socioecological research (Bérard et al., 2011; Bernués et al., 2011; Elmqvist et al., 2003; Kizos et al., 2014; Knox & Clarke, 2012). Since its first definition, resilience, or lack of, has been related to the inner complexity of ecosystems (Cabel & Oelofse, 2012; Gunderson, 2000; Walker & Meyers, 2004); it is the result of the multiple interactions between different processes, and their feedbacks. Resilience of ecosystems, however, can be significantly modified by human activities and their interactions with disturbance events and natural processes (Sporton, 2007). Current scientific knowledge does not view resilience as a static property; ecosystems can have multiple equilibrium states (or configurations), each of which has its own stability landscape (Gunderson, 2000; Scheffer *et al.*, 2009; Walker *et al.*, 2004). Moreover, according to the panarchy framework (Walker *et al.*, 2004), each system evolves as a result of the interactions occurring at multiple scales (Davoudi *et al.*, 2012; Groffman *et al.*, 2006). Resilience of ecosystems thus can contribute to the long-term sustainability of socioecological systems, allowing for recovery, adaptation, and transformation in the face of shocks and sudden changes (Domptail *et al.*, 2013). Resilience is also used in social studies and human geography, to refer to the capacity of social structures to cope with disturbances and shocks. While some authors attempt to transfer the ecology-based definition to the human domain, others focus on aspects that are distinctive to human systems, such as learning capacity, agency, and power relations (Wilson, 2017).

Land management is defined as the specific combination of practices through which land is used (Hurni, 2000). It is different from "land use", which is the objective or purpose for which land management is implemented (FAO & UNEP, 1999) and which refers to broader categories such as cropland, grazing land, or forest land. Land management practices (LMPs) are normally implemented to increase productivity of the land or to reduce degradation associated with human activities. Through land management, humans can also change the resilience of ecosystems (Alados *et al.*, 2011; Crépin *et al.*, 2012; Folke *et al.*, 2010; Jucker Riva *et al.*, 2016): Successful LMPs can make it more difficult for an ecosystem to reach a critical threshold (e.g. reducing the frequency of fires in a forest area prevents a shift to shrub-dominated vegetation). Further, LMPs can reduce the impact of disturbances (e.g. increasing vegetation reduces erosion during torrential rainfall) or directly move the system towards a more stable configuration (e.g. afforestation after a fire in case of failed spontaneous recovery). Adapting LMPs to increase resilience to disturbances – so-called "resilience thinking" (Plummer & Armitage, 2007; Rist & Moen, 2013) – is in most cases preferable to changing the land use as a whole, which would require great efforts and have highly uncertain ecological and socio-economic impacts, possibly affecting the livelihoods of local communities. While a wide set of methods and tools exist to assess how LMPs affect sustainability of land use (Bunning *et al.*, 2011; ELD Initiative, 2015; WOCAT, 2008), there are few studies that focus on how LMPs influence the resilience of ecosystems. The few such studies that exist are very case specific (e.g. valid only for a certain event or area) or context specific (e.g. valid only for a certain type of disturbance). Thus, despite efforts to operationalize the resilience of ecosystems to avoid the loss of ecosystem services (Bergamini *et al.*, 2013; Mitchell *et al.*, 2014; Plummer & Armitage, 2007; Resilience Alliance, 2010), it remains difficult to identify practical solutions for land managers, as the value of a certain LMP may vary greatly if we consider only the degradation caused by land use or if we include increasing resilience to disturbances within the management objectives (Jucker Riva *et al.*, 2016). Therefore, there is a need to increase our understanding of how LMPs can contribute to resilience. There is also a need for practical methodologies to evaluate the role of land management, to avoid a decrease in resilience and to achieve cost-effective management strategies, thus increasing long-term sustainability.

LMPs are often difficult to assess, as the impact of practices can be extremely diverse even within the same area, depending on the timing, location, and conditions of the environment in which they are implemented (Liniger *et al.*, 2017; Schwilch *et al.*, 2011). Systematic information on the application and impacts of practices is often lacking and difficult to compare. Moreover, the value of LMPs also depends on their economic sustainability and cultural acceptability (Hurni, 2000); thus, the perception of different actors is extremely relevant. Co-creation of knowledge, also known as transdisciplinary research (Hadorn *et al.*, 2006; Mauser *et al.*, 2013; Pohl & Hirsch Hadorn, 2007; Regeer & Bunders, 2009), is an innovative approach to address complex environmental issues. It stems from the idea that multiple types of knowledge exist beyond conventional science, and that they can be combined (Bautista *et al.*, 2017; Reed *et al.*, 2008; Regeer & Bunders, 2009; Tabara & Chabay, 2013). It consists of a process in which scientists from different disciplines and stakeholders actively exchange and combine information on a certain topic. This approach has been applied successfully to the assessment of LMPs in multiple ecosystems around the globe (Liniger *et al.*, 2013; Liniger & Schwilch, 2002; Pohl *et al.*, 2010; Schneider & Rist, 2014; Schwilch *et al.*, 2009, 2012, 2013). Not only is the perception of stakeholders considered in the assessment, but also their knowledge and experience about the land is used to contextualize data and fill information gaps that may arise during the assessment. This knowledge co-creation approach is in line with recent approaches to resilience studies (Bergamini *et al.*, 2013; O'Connell et al., 2016; Plummer & Armitage, 2007; Rist & Moen, 2013; Sporton, 2007; Walker *et al.*, 2010): the focus is on gathering and combining existing knowledge (Resilience Alliance, 2010), using methodologies based on self-evaluation (Choptiany *et al.*, 2016), participation (Cumming *et al.*, 2005; Dixon & Stringer, 2015), and/or active exchange between scientists and land managers (Domptail *et al.*, 2013; Mitchell *et al.*, 2014). Finally, the approach is often integrative and interdisciplinary (Cabel & Oelofse, 2012; Sporton, 2007).

3. Methodology

In this study, we focus on the resilience of semi-natural Mediterranean ecosystems in relation to multiple disturbances that can reduce the provision of ecosystem services, so-called "specified resilience" (Folke *et al.*, 2010) or "resilience of what to what" (Carpenter *et al.*, 2001). Each study site presents a different combination of LMPs and disturbances, as well as varying amounts/types of available scientific knowledge (e.g. literature or measurements) versus stakeholder knowledge. This means that we could not define specific indicators to assess the contribution of LMPs to the resilience of the ecosystem in advance. In order to have a systematic and reproducible methodology that could be implemented across different study sites, we chose to define a series of questions to be answered by a team of researchers, by consulting available scientific knowledge and discussing with stakeholders. Results concerning the role of LMPs were then translated into a semi-quantitative evaluation and combined in a single assessment using a mathematical index.

A synthetic assessment of the resilience of ecosystems is challenging because resilience is an emergent property, therefore it is influenced by multiple processes that are difficult to capture in a single evaluation (Domptail *et al.*, 2013; Gunderson, 2000). Furthermore, different perceptions are involved in land management assessments, adding to the complexity of understanding resilience. Complex evaluations are however difficult to communicate and use, and reliance on simplified indices is a widely acknowledged technique in applied research projects (Costantini *et al.*, 2016; Helldén & Tottrup, 2008; Mcdonagh *et al.*, 2009; Mumby *et al.*, 2014; Pyke *et al.*, 2013). Throughout our study we navigate between opposite needs: to generalize in order to obtain a usable methodology and results that would be relevant beyond the specific case, and to contextualize to have a meaningful assessment. Generalization is obtained by framing common questions and pre-defined answers that can be answered through both scientific and stakeholder knowledge, by cross-site comparison of results, and by grouping the LMPs by type. Contextualization is obtained by considering the land management system, including stakeholder perception and knowledge, and focusing on specific ecosystem services.

In a preliminary phase of the research, we described a list of promising and common LMPs in the different study sites using the WOCAT technology questionnaire (WOCAT, 2008), and identified the respective land management systems, i.e. the land managed through a specific set of LMPs, by the same group of actors for a specific purpose. This allowed us to unambiguously identify the area of interest, the set of management practices, and the actors involved in the management that constituted the pool of stakeholders that were invited to participate in the assessment. Moreover, we proceeded to design the questionnaire using an iterative and participatory process (figure 1 and Method S1). The questionnaire (named Resilience Assessment Tool, or RAT, see Appendix S2) includes a characterization of the state of the system (e.g. state of most important ecosystem services and ecological features) according to land users' perceptions, types of disturbance and their impact on ecosystem services, role of land management in modulating the negative impact of disturbances, and external factors that could influence the dynamic of the land management system (e.g. policies, socio-economic context, climatic trends). Answers are provided by choosing an option on a pre-defined list and adding details and comments in free text.

The first step of the implementation phase centred on engaging a comprehensive pool of stakeholders in participating in the assessment. To do so, we proceeded in a cascade way from the stakeholders that were already in contact with the researchers, from the preliminary phase of the research, to all the land users, land managers, and local administrators directly involved in the land management.

To increase reproducibility and comparability of results across site, we restricted the pool of stakeholders to those with a tangible influence on the land management of each study site, and aimed at consulting at least 10 stakeholders belonging to at least three different categories (land managers, land users, local administrators, experts/consultants). As many of the study sites are located in areas subject to land abandonment and outmigration, we had to reduce the number of people consulted; in one study site (Por_2, *Traditional logging*), the stakeholder group was limited to four. With such a low number of stakeholders the results may not be representative for the greater area, but they accurately reflect the views of those most directly involved with the land. Overall, 57 stakeholders (between three and 12 stakeholders per site) agreed to participate in workshops together with one or two researchers per study site. Information resulting from the first workshop was complemented and crosschecked with data obtained from local monitoring programmes, scientific literature, and direct observation by participating scientists. Inconsistencies and knowledge gaps were addressed by again consulting the stakeholders and local experts. Results were subsequently reviewed by an external group of researchers to ensure that complete and systematic answers were provided to each question. A complete list of sources used is presented in table S3.

After completing and reviewing all the questionnaires, we ranked the answers to questions of the RAT closely related to the contribution of LMPs to the resilience of the land management systems we studied. These questions related to: (1) the impact of disturbances on ecosystem services that were identified as important (D) by stakeholders during group discussions (see Appendix S2, section 2); (2) the influence (I) of land management in preventing a disturbance (p), mitigating its negative effect (m), or fostering recovery (v) of the ecosystem's ability to supply important services (see Appendix S2, section 4); and (3) the resistance of an LMP to a disturbance (r), i.e. the extent to which the effectiveness of an LMP changes after the occurrence of a disturbance (see Appendix S2, section 4.3). Questions in the RAT were multiple-choice, with space in text boxes to justify the choice and provide further details for interpretation. These three evaluations (D, I, and r) were merged into a single resilience index (R) to assess the contribution of each LMP to the resilience of the land management system to a specific disturbance. Examples for each variable considered in the assessment are presented in table 1, while a detailed explanation of how the resilience index was calculated is presented in the following paragraphs.

Insert table 1

3.1. Impact of disturbances

To assess the impact of disturbances on ecosystem services, we first identified which ecosystem services are considered important by land managers. We relied upon the perception of stakeholders participating in the assessment, using the list of ecosystem services adapted from the WOCAT Technology questionnaire (WOCAT, 2008) and widely used for this kind of participatory assessment. The information was collected during group discussions using section 2 of the Resilience Assessment Tool (See Appendix S2, page 9, question 2.1 and 2.1.1). The ecosystem services are classified as "productive", "ecological", and "socio-cultural" and roughly correspond to the "provisioning", "regulating", and "cultural" categories used in the Millennium Ecosystem Assessment. Then, using both scientific and lay knowledge, we identified the ecosystem services that were likely to be degraded by each disturbance (See Appendix S2, section 4.1.3). The *Impact D* of the disturbance *j* was quantified through equation 1:

$$D_j = ES_j/ES \qquad \text{(Eq. 1)}$$

where ES is the number of ecosystems services identified as important by stakeholders, and ES_j is the number of ecosystem services affected by the j^{th} disturbance (among those services considered important). Equation 1 gives a number between 0 (no impact on important services) to 1 (all important services are affected).

3.2. Influence and resistance of Land Management Practices

By combining the information provided by the stakeholders with the scientific data available, we evaluated the influence of each LMP in (a) preventing a disturbance; (b) mitigating the negative impacts of a disturbance on the land management system; or (c) fostering recovery. This evaluation was conducted through answers to the following questions: "*Does the LMP reduce the occurrence of disturbances?*"; "*Does the LMP mitigate the negative effect of disturbances?";* "*Does the LMP help recover/restore the system after a disturbance?* (See Appendix S2, section 4.2)*"*. For the quantitative evaluation, we considered prevention, mitigation, and recovery as equal. This differs from the usual approach to land degradation, which considers prevention to be more important. We chose not to consider prevention as more important because some disturbances cannot be prevented through land management (e.g. droughts, floods). Moreover, ecological studies suggest that preventing the occurrence of a disturbance may in the long run make the ecosystem less resilient. (Carpenter *et al.*, 2001; Merriam *et al.*, 2006; Oliveira & Fernandes, 2009)

The answers were transformed into values, derived from the pre-ranked list of five possibilities, ranging between -2 (degradation has heavily increased or recovery is prevented) and 2 (degradation is minimal or recovery is ensured). We combined the values related to prevention, mitigation, and recovery to obtain a single number indicating the direct influence of land management on the resilience of the system. Considering that prevention, mitigation, and restoration strategies are equally weighted, the influence (I) of an LMP i on the disturbance j is calculated as per equation 2:

$$I_{i,j} = p_{i,j} + m_{i,j} + v_{i,j} \qquad \text{(Eq. 2)}$$

where $I_{i,j}$ is the influence of the i[th] LMP on the j[th] disturbance identified for the land management system, and $p_{i,j}$, $m_{i,j}$, and $v_{i,j}$ are, respectively, the influence of the i[th] LMP in preventing, mitigating, or assisting recovery from the j[th] disturbance. As $p_{i,j}, m_{i,j}$ and $v_{i,j}$ have values between -2 and 2, equation 2 results in a numerical value between -6 to 6, where negative values correspond to net negative effects of land management in relation to a disturbance (increase in occurrence or in the related degradation), 0 corresponds to a negligible effect or a balanced combination of positive and negative effects, and positive values indicate a beneficial net effect of the practice. In this paper, we will use the term "positive" to refer to practices that increase resilience to a disturbance through prevention, mitigation, or recovery and the term "negative" to refer to practices decreasing the resilience of the ecosystem to a disturbance.

We also investigated resistance of LMPs to disturbances, i.e. any change in their effectiveness following the disturbance, using both scientific knowledge and stakeholder perception Assessing the resistance of LMPs to disturbances ($r_{i,j}$), allows us to understand how the effectiveness of LMPs can change as a consequence of the disturbance itself. Identifying such feedbacks is extremely important to understanding resilience (Carpenter *et al.*, 2009; Folke *et al.*, 2004; Mitchell *et al.*, 2014)., particularly for semi-natural ecosystems that are often of low economic value: in such cases, investments in land management are limited, especially in maintaining a practice. The resistance $r_{i,j}$ of a practice *i* to a disturbance *j* was assessed as a penalty to the influence *I* on a point scale of 0 (the practice is as effective after as before the disturbance) to 3 (the effectiveness of the practice is negatively affected by the disturbance, leading to increased degradation). We adapted equation 3 so that a small beneficial influence of the LMP on the resilience of the ecosystems could be offset by a low resistance of the LMP to the disturbance. This choice was based on the fact that, in most cases, one or two disturbances have occurred since the implementation of the LMP. This might not be appropriate for studies involving much longer timespans or disturbances with a more frequent occurrence.

To enable cross-site comparison of the influence and resistance of similar LMPs, in the following text we have aggregated the values of *I* and *r* by type. In all cases, the arithmetic mean values are used.

3.3. Overall resilience assessment

Finally, we combined the impact of disturbances D_j, the influence of LMPs $I_{i,j}$, and the resistance of practices $r_{i,j}$ in an index using Equation 3 to calculate $R_{i,j}$: the contribution of each LMP *i* to the resilience of the land management system against the disturbance *j*. Considering that $I_{i,j}$ cannot be below the maximum negative effect of the influence of land management, $R_{i,j}$ is calculated as:

$$R_{i,j} = D_j \,(I_{i,j} - r_{i,j})/k \qquad (3)$$

where the value of *k* is 6, when $-6 \leq (I_{i,j} - r_{i,j}) \leq 6$, or 9 when $(I_{i,j} - r_{i,j}) < -6$. Eq. 3 results in a value between -1 and 1, where all negative values indicate that the practice has a detrimental effect on resilience, 0 indicates a null or balanced effect, and positive values indicate a positive contribution of the LMP to resilience of ecosystems.

In order to evaluate the combination of LMPs used in the study site, we aggregated the values of *R* by land management system using the arithmetic mean.

3.4. Study sites

Our study focuses on eight sites in five countries in southern Europe (figure 2), where regime shifts have occurred or are likely to occur in the near future, due to anthropogenic or climate pressure. They are semi-natural ecosystems, dominated by Mediterranean forests and shrublands, but with a long history of land use that includes cropping. They are characterized by a variety of climatic conditions, from humid (Por_1 and Por_2) and sub-humid (Spa_2, Spa_3, Ita_1, Gre_1), to semi-arid (Spa_1, Cyp_2). All study sites except Spa_1 (Restored shrubland) and Spa_3 (Diversified shrubland) are still used for production: animal farming in the shrub-dominated areas (Ita_1, Gre_1, and Cyp_1), and wood production in the others (Por_1 and Por_2, and Spa_2 to lesser degree). All the study sites are affected by disturbances that have generated or are likely to generate long-term changes in the ecosystem, decreasing the supply of ecosystem services. All LMPs identified, with the exception of those in Por_1 and Por_2, had been implemented for a minimum of 10 years before this study began.

Insert figure 2

Another difference among the study sites is related to the respective main objectives of land management (table 2). These range from maximizing productivity (Por_2 *Traditional logging*) to reducing the impact of land use (Por_1 *Conservation logging*, Cyp_1 *Extensive grazing*) or restoring the ecological or productive value of the land (Spa_1 *Restored shrubland*, Spa_2 *Restored forest*, Gre_1 *Silvopastoral system*). Among their management objectives, three of the land management systems specifically include resilience or dealing with disturbances: Spa_3 *Diversified shrubland*, Ita_1 *Seasonal pasture* and, at least in part, Spa_2 *Restored forest*.

Insert table 2

4. Results

Throughout the eight study sites we identified a total of 16 LMPs (table 3) that were implemented prior to our study, either in combination (five study sites) or alone (three study sites). To extrapolate general indications and compare the contribution of LMPs to resilience across the sites, we grouped them according to the type of practical actions involved in each practice (table 3). Detailed description of LMPs is presented in table S4. In brief, *Clearing of vegetation* is aimed at reducing the biomass in fire prone areas. When implemented in forests, the wood extracted can be used for production. *Grazing management* focuses on regulating the access of animals that graze in a certain area throughout the year (Ita_1) or in particularly vulnerable periods (Gre_1). *Planting of shrubs* is a restoration practice for degraded areas, aimed at increasing vegetation cover and thereby reducing soil erosion, increasing fertility, and triggering the natural evolution of the ecosystem. *Planting of trees* is used both in forest areas (Spa_2) and in rangelands (Gre_1, Cyp_1) as a restoration measure. Finally, under *Other*, we classified two practices used in Cyprus, *Carob tree protection from rats* and *Fodder provision to animals during summer*, to mitigate degradation caused by grazing and pests.

Insert table 3

4.1. Disturbances and impact on the supply of ecosystem services

The first step in evaluating the impact of disturbances to ensure compatibility with the perception of stakeholders, focused on identifying the most important ecosystem services for them (table 4).

Insert table 4

In half of the study sites, both "productive" and "ecological" services were indicated as valuable, while in only two of them no productive services were deemed valuable. Among the ecological services, "reduced erosion" is the most frequently indicated (six out of eight study sites), followed by "above-ground biodiversity" (four out of eight) and "protection from extreme events". Sociocultural services are the ones least considered, with no study site indicating both recreational and cultural services.

Having identified the most important ecosystem services, we evaluated how each disturbance could affect them using eq. 1 (table 5).

Insert table 5

In seven out of eight study sites, more than one disturbance was reported as likely to decrease the provision of important ecosystem services. The disturbances most commonly reported were also those with the greatest impact: droughts and wildfires. *Wildfire* affects not only the forest systems but also the pastoral ones. Exceptions include *Restored shrubland* (Spa_1) and *Seasonal pasture* (Ita_1). The second most commonly reported disturbance is *drought*, affecting five of the eight land management systems. Third are outbreaks of *pests and diseases*, including plant diseases (e.g. nematodes and Tomicus beetles in forests), animal diseases (in grazing systems), but also animal pests: Ita_1 pastures are affected by wild boars that disrupt the grass layer; Cyp_1 shrublands are affected by brown rats, which attack the carob trees, increasing their mortality. *Torrential rainfalls* refers to heavy rains that create significant concentrated erosion rills, and can trigger the creation of gullies. *Floods* refers to a temporary inundation of the area due to overflow from neighbouring streams.

4.2. Influence of LMPs on disturbances

The second step in assessing the contribution of LMPs to the resilience of forest and rangeland consists of evaluating how LMPs influence the system when a disturbance occurs $I_{i,j}$, and how they are affected by the disturbance $r_{i,j}$. Values of $I_{i,j}$ above 0 identify LMPs as "positive" (increasing resilience to a disturbance), while Values of $I_{i,j}$ below 0 indicate a "negative" influence (decreasing resilience). $r_{i,j}$ values below 1 identify an LMP as "non-resistant". The results of both evaluations are presented in figure 3.

Insert figure 3

Most LMPs assessed have a positive influence on the disturbances studied (i.e. they reduce the land degradation caused by the disturbance), with the exception of *Grazing management*, which was the only LMP assessed to have a negative influence on resilience (drought). All the practices appear to have very different levels of influence and resistance depending on the disturbance considered. In particular, *Grazing management practices* were considered *positive and resistant* only in relation to pests and diseases, *negative but resistant* in relation to droughts, and *positive but not resistant* in relation to fires. *Clearing of vegetation* was judged to be positive not only against wildfires and pests and diseases but also in relation to droughts. In grazing systems *Planting of trees* was judged *positive* *and resistant* in relation to floods, but *not resistant* in relation to droughts and scarcely resistant to fires. Similarly, *shrub planting* was assessed to have a positive effect on the ecosystem's resilience to fire, and to a lesser degree, torrential rainfall, but negative effects on resilience to drought and flood.

4.3. Overall contribution of land management practices (LMPs) to resilience of ecosystems

Having assessed the impact of disturbances on the land management system and the influence of LMPs when a disturbance occurs, we can now evaluate the overall contribution of LMPs to the resilience of the land management system using eq. 3 (table 6 and figure 4.)

Insert table 6

Most practices were assessed as having a positive impact on the resilience of the land management systems in which they were implemented, in relation to at least one disturbance. The removal of vegetation (*Selective clearing* in Spa_2, *shrub clearing* in Spa_3) was assessed to be very positive for resilience (average R value: 0.45). Moreover, *Traditional logging* in Por_2 (average R value: 0.17) was assessed as more resilient than *Conservation logging* in Por_1 (average R value: -0.125), the former involving more vegetation removal than the latter. Planting of vegetation was assessed as mostly detrimental to resilience: *Afforestation with P. halepensis* in Spa_2 appears to have a negative role in relation to fires (R value: -0.33), as does the *resprouter shrub plantation* in Spa_1 against droughts (R value: -0.33). In rangeland systems, the *Fences* adopted in the Italian study site appear to be very effective against pests. *Carob afforestation* scores a higher value against fire in the *silvo-pastoral system* (*Gre_1*) compared to *extensive grazing (Cyp_1*).

Insert figure 4

When considering the combined contribution of LMPs to the resilience of their land management system, *seasonal pasture* (Ita_1, R value: 0.33), *diversified shrubland* (Spa_3, average R value: 0.19), and *restored forest* (Spa_2, average R value: 0.11) were assessed as the most positive case studies. Only *Conservation logging* (Por_1, average R value: 0.13) was assessed to decrease the overall resilience of the system. However, in six out of eight study sites, LMPs had some negative impacts on resilience. In particular, *restored forest* in Spain (Spa_2), where selective cutting and planting of fire resilient species was applied, scored the lowest and the highest values (-0.33 and 0.67 respectively, table 6) of the whole assessment. Among the forest systems, it appears that the LMPs of the *restored forest* (Spa_2) contribute most to the resilience of the system.

5. Discussion

5.1. Methodological approach to resilience assessment

Our methodology was based on an integrative approach (Mauser *et al.*, 2013) directed at combining, rather than dissecting, knowledge and information. This applies mainly to the study of the role of LMPs: we assessed the outcome of a certain practice implemented in a certain context in relation to a certain disturbance, without analysing separately each variable that leads to such outcome. This may have led to a difference in the assessment across different study sites, since there is some indication that the effects of practices may depend on the conditions of the system itself before the disturbance (Walker *et al.*, 2010) and other contextual factors such as the landscape (Jucker Riva *et al.*, 2017) and time of implementation (Jucker Riva *et al.*, 2016). An example was the different evaluation of *Carob plantation* with regards to fire in Cyprus and Greece. The contextual information about the land management systems collected through the Resilience Assessment Tool enabled us to explain differences not captured through the numerical evaluation. We also tried to capture stakeholder perception in an integrative way, i.e. by encouraging different actors to share and confront their views with others during group discussions. This approach allowed us to obtain a unified picture of stakeholders' perceptions, but did not expose underlying power relations or agendas that might have influenced the participatory process.

The first step of our analysis focused on identifying which ecosystem services are to be maintained or restored. This approach allowed us to clearly evaluate the impact of disturbances across different study sites, but it does not integrate all the possible ways a system can cope with disturbances (Briske *et al.*, 2010; Gunderson, 2000; Mumby *et al.*, 2014). Rather than focusing on resisting, recovering, or adapting the land management, in certain cases it may be worthwhile transforming (O'Connell et al., 2016; Walker *et al.*, 2004), (i.e. changing) the land use entirely in order to make use of a different set of ecosystem services, which may arise after a disturbance or may turn out to be more stable. A separate study should be carried out to evaluate the possibilities, advantages, and disadvantages of transforming the land use system to one that is less affected by disturbances, involving different stakeholders, processes, and scales.

5.2. Assessing the Influence ($I_{i,j}$), Resistance ($r_{i,j}$) and overall contribution of LMPs to Resilience of ecosystems ($R_{i,j}$)

From our assessment of the resistance of LMPs, revegetation practices such as *shrub* and *tree planting* are more at risk of collapsing after a disturbance: *Afforestation with pines* and *shrub planting* were assessed to be particularly vulnerable to both droughts and fires. The value of these practices is highly debated among scientists (Maestre & Cortina, 2004a; Pausas *et al.*, 2004; Vallejo *et al.*, 2012), especially if they are not combined with other practices that focus on increasing resilience (Seidl *et al.*, 2016).

In order to compare and combine results across study sites, we chose to calculate the contribution of each LMP to resilience (*R* value, see equation 3) separately, even if the practices are usually implemented in combination (e.g. *Tree planting* and *Clearing of vegetation* in Spain vs. *Tree planting* and *Controlled grazing* in Greece). With the exception *Restored shrubland* (Spa_1), the practices implemented over the same study site are of very different types, making it possible to distinguish the effects of one from the other. For example, in the case of *Restored forest* (Spa_2), management consists of three LMPs of two different types: *Planting of trees* (pine afforestation) and *Clearing of vegetation* (fuel breaks and selective clearing, see table 3). *Planting of trees* and *Clearing of vegetation* entail opposing interactions with the environment, and thus it was easy to identify the influence of afforestation on resilience. Fuel breaks are implemented at specific sites only, while selective clearing is implemented over wide areas, so it was possible for both land managers and scientists to distinguish the role of one practice from the other by comparing different sites within the forest stand.

Our results show how double-edged the contribution of LMPs to resilience can be, depending on the disturbance type and the context. *Carob plantation* was assessed as increasing the resilience against fire in Greece (R value: 0.13) but decreasing it in Cyprus (R value: -0.08) due to a difference in context: in Cyprus, the average biomass density of the shrublands is much lower, and so planting carob could increase the amount and continuity of fuel present; in Greece, the fuel amount and connectivity of vegetation are higher, and so the presence of carob does not further increase the risk of fire. Thus, *Carob plantation* increases resilience to drought (Gre_1, Cyp_1) but can reduce resilience to fire (Cyp_1).

The wide range of scores obtained by LMPs in relation to drought and fire (e.g. Spa_2, 0.75, see table 6) suggests that increasing resilience to both disturbances at the same time could be difficult, as practices aimed at dealing with fire reduce resilience against drought. This is very relevant because the two disturbances are often linked, and one tends to reinforce the other (Bigler *et al.*, 2005). Scientists have previously stressed the importance of considering multiple disturbances at once (Buma & Wessman, 2011; Turner, 2010), but it is difficult to find studies that propose practical solutions. *Selective clearing* increases resilience to fire and drought, respectively, by reducing the flammable biomass and by increasing the water available per individual plant (Spa_2, Spa_3). In grazing areas, *Fodder provision* appears to have positive impacts on resilience, regardless of the disturbance affecting the system. In general, no single practice was able to increase resilience to all disturbances while maintaining its effectiveness. The highly variable scores obtained by all the practices in relation to different disturbances suggest that multiple practices are needed to tackle the full spectrum of disturbances that may harm an ecosystem.

The results of our assessment are consistent with a separate study (Valdecantos *et al.*, 2016) based on the Landscape Function Analysis procedure of Tongway & Hindley (2004). The other study was carried out in the same sites comparing an undisturbed area, a degraded area, and an area that had been managed or restored. Consistent with our results, the study by Valdecantos et al. found that *Traditional logging* in Portugal appeared to improve ecosystem services supply more than *Conservation logging*, *Tree planting* in Cyprus and Greece improved water infiltration and nutrient cycling and reduced erosion, *Selective Clearing and planting* in shrubland in Spain improved biodiversity and permanently reduced fuel load. The systems that scored the highest values from our assessment are indeed those that explicitly include dealing with disturbances among their management objectives: *Seasonal pasture* in Italy; *Diversified shrubland* and *Restored forest* in Spain. In our interpretation, the high scores of the land management systems Ita_1, Spa_3, and Spa_2 are related to the fact that the practices implemented aim at reducing the impact of the most relevant disturbances; in other words, resilience is among the objectives of the land management strategy.

5.3. Resilience values by type of practice and land management system

After the assessment we classified the practices by type, and proceeded to combine the results of the assessment by type of practice and by land management system. This step was essential to draw conclusions about the overall contribution of land management to the resilience of each study site, and enable a cross-site comparison of practices (e.g. tree planting in Spain and Cyprus).

When considering the combination of LMPs implemented in each study site in relation to multiple disturbances, management strategies addressed at improving the environment did not necessarily prove valuable for increasing resilience. Restoration practices belonging to the *planting of trees* type were considered *not resistant* to droughts and fires. This casts doubt over the long-term effectiveness of this type of practice when implemented in drylands that are frequently affected by those disturbances (Maestre & Cortina, 2004b; Pausas *et al.*, 2004). The detrimental influence of *Conservation logging* is particularly interesting: the dead woody material left on the ground reduces soil erosion by rain, but it also increases the chances of both fire and disease outbreaks, decreasing the resilience of the system (Prats et al., 2012). The negative influence on resilience scored by *Grazing management* was unexpected, as moderate grazing has been reported to favour ecological functioning and the overall provision of services in Mediterranean rangelands (Papanastasis *et al.*, 2015), and to reduce fuel load and competition between plants. However, while a given grazing intensity could be adequate for periods under normal climatic conditions, the combined pressure of grazing and drought may increase plant mortality above a critical threshold and trigger ecosystem collapse (He *et al.*, 2017). Furthermore, grazing- and drought-induced mortality may be higher for palatable grasses and wide-leafed shrubs than for unpalatable species, leading to a decrease in fodder value even after a resting period during which a pasture is not used for grazing (Caldeira *et al.*, 2015). Only *Clearing of vegetation* scored high values against multiple disturbances. Indeed, a selective and partial clearing of vegetation reduces fuel load (relevant for resilience against fire), favours the growth of the remaining plants, and reduces the competition for water among individuals – all of them factors that favour recovery of ecosystems in a wide variety of situations (Baeza & Vallejo, 2008).

5.4. Relation between resilience and sustainability

Resilience of ecosystems is considered by some scientists to be part of sustainability (Hurni, 2000). In practice, however, we have detected a conflict between reducing land degradation and managing for resilience: *Conservation logging* applied in Portugal to reduce the impacts of logging on soil was revealed to be far less beneficial to resilience than *Traditional logging (*figure 4). This, together with the shortcomings identified for *tree* and *Shrub planting,* highlights the risks and uncertainties associated with strong interventions aimed at controlling or modifying specific aspects of the ecosystem (Domptail *et al.*, 2013; Hilderbrand *et al.*, 2005). In accordance with recent research, it appears that allowing for self-organization (Bergamini *et al.*, 2013; Choptiany *et al.*, 2016; Peterson, 2000), e.g. through selective vegetation removal, is far more beneficial. Diversity, often associated with increased resilience in scientific literature (Acácio & Holmgren, 2014; Bennett *et al.*, 2015; Elmqvist *et al.*, 2003; Lavorel, 1999) appears to be relevant for our study: the enhanced species diversity after *Shrub planting* in Spa_1 and Spa_3 increased the resilience of land management systems in Spa_1 and Spa_3; since few LMPs proved beneficial against multiple disturbances, an increase in resilience could be achieved by diversifying the management. Finally, our results appear to support the "resilience thinking" approach (Folke *et al.*, 2010; Mitchell *et al.*, 2014; Rist & Moen, 2013; Walker & Salt, 2012): land management systems that included increasing resilience or coping with disturbances among their management objectives proved to be more successful in increasing resilience of ecosystems.

6. Conclusion

Our study focuses on the role of land management practices (LMPs) in relation to the disturbances that affect several Mediterranean ecosystems, using information collected through a knowledge co-creation approach evaluated through a synthetic, semi-quantitative index. By evaluating the land management options in detail, we are able to highlight important practical information for land managers to increase the resilience of their ecosystems. Our spatially explicit definition of land management systems allowed us to study both the natural environment and human actions, and is flexible enough to be adapted to a wide variety of areas. Involving stakeholders allowed us to not only include different perspectives, but also to overcome knowledge gaps and missing information that would have required long-term monitoring and field observations.

The results of our assessment revealed that the practices analysed are particularly effective against wildfires and torrential rainfalls. By contrast, droughts are more difficult to counter and all LMPs were heavily affected by their occurrence. The effectiveness of LMPs belonging to the *Tree planting* group appears highly sensitive to disturbances, calling into question their value in areas that are frequently affected by disturbances. By contrast, LMPs that selectively reduce the amount of vegetation appear to be beneficial in fostering recovery of ecosystems. Furthermore, our assessment suggests that there are potential incompatibilities among land management objectives: increasing resilience of ecosystems to drought appears to reduce resilience to fire, and reducing the impact of logging in forests appears to reduce resilience to fire and pest outbreaks.

From our study, we have derived several practical indications of how to increase the resilience of Mediterranean ecosystems threatened by disturbances, relevant for land management planning and policymaking. First, promote the use of multiple (rather than few) ecosystem services, as this makes disturbances less impacting for land users. Second, implement multiple land management practices, focused on preventing, mitigating, or fostering recovery in relation to different disturbances, because single LMPs fail to provide benefits in relation to different disturbances, especially if both drought and fire are likely to occur. Third, consider the resistance of LMPs and act to restore their effectiveness if needed, as LMPs may cease to provide benefits and even cause harm to the ecosystem after a disturbance has occurred. Fourth, carefully consider the long term value of heavy restoration interventions such as pine afforestation, since they are heavily impacted by disturbances.

The methodology used in this study allowed us to synthetically evaluate the combined effect of different LMPs in relation to several disturbances. Furthermore, the methodology could be integrated into sustainability assessments and land management planning tools to facilitate “resilience thinking”. To enhance the robustness of results and their applicability across different ecosystems, future studies should include specific indicators for ecological processes that influence resilience to different disturbances.

7. Acknowledgements

For their contribution and help in gathering information, we thank Costas Michael from the Department of Agriculture and Adamos Markides from the Department of Forest (Cyprus); Miquel G. Bartual, Alberto Vilagrosa, Esteban Chirino, and Daniel Ferrández (Spain); Sandra Valente, Celeste Coelho, Oscar González-Pelayo, Victor Santana and Paula Maia, Eng. Rui Melo (Director) and Eng. Rui Pedro Ferreira of the Institute for the Conservation of Nature and Forests (Portugal); Ioanna Panagea, Dr. Marinos Kritsotakis, Kostas Karatzis (Greece); Velia de Paola (University of Basilicata, Italy). We thank Tina Hirschbuehl and Anu Lannen for the language editing and the anonymous reviewers for their detailed comments.

This paper was developed within the CASCADE project (Seventh Framework Programme FP7/2007–2013 grant agreement 283068). For their financial support we thank CESAM (UID/AMB/50017), FTC/MEC, FEDER and PT2020 Partnership Agreement (Portugal); Generalitat Valenciana (DESESTRES – program PROMETEO II/2014/038, Spain), Compete 2020 and ESSEM COST Action ES1104.

8. Supporting information:

Method S1. Design process of the Resilience Assessment Tool and interactions with different stakeholder groups

Appendix S2. Resilience assessment Tool

Table S3. Sources used to assess the contribution of land management to resilience of Mediterranean forests and rangelands

Table S4. Detailed description of land management practices assessed

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Table 1. Description of the variables considered in the resilience index and examples of high and low values

Variable	Description	Low values	High values
Impact of disturbances (D_j)	Impact of the disturbance on important ecosystem services	The disturbance reduces the supply of few ecosystem services where many are considered important. E.g. Pine disease outbreak (nematodes) reduces timber production in a forest considered important also for biodiversity, landscape value, and greenhouse gas absorption	The disturbance reduces the supply of the few ecosystem services considered important, or impacts multiple ecosystem services. E.g. fire damages or destroys the trees in a forest stand considered important only for timber production
Prevention ($p_{i,j}$)	Influence of the LMP in increasing or reducing the frequency and intensity of a disturbance	The LMP increases the frequency of the disturbance. E.g. Pine afforestation increases likelihood of fires	The LMP reduces frequency or intensity of the disturbance. E.g. Selective clearing reduces flammable biomass decreasing fire intensity
Mitigation ($m_{i,j}$)	Influence of the LMP in increasing or reducing the degradation caused by a disturbance	The LMP increases the damage caused by the disturbance. E.g. limiting grazing animals' movement during drought increases damage to vegetation suffering from drought	The LMP reduces the damage caused by the disturbance. E.g. Planting shrubs on terraces reduces speed of surface water, decreasing damages caused by floods
Recovery ($v_{i,j}$)	Influence of the LMP in increasing or reducing the speed of the ecosystem's recovery after a disturbance	The LMP prevents or slows down recovery of the ecosystem. E.g. logging after a fire damages the seeds located in the soil (seed bank), preventing the growth of new trees	The LMP speeds up or facilitates recovery of the ecosystem. E.g. carob plantation improves soil fertility and reduces erosion after a fire, facilitating recovery of vegetation
Resistance ($r_{i,j}$)	Effectiveness of the LMP after the occurrence of a disturbance	The LMP is as effective after the disturbance as it was before. E.g. protection of carob trunks after a drought	The LMP is not effective after a disturbance or effects negatively the functioning of the ecosystem. E.g. planted shrubs die during a drought, increasing the flammable biomass and thus the risk of fire

Table 2. Main features of the land management systems studied derived from section 1 of the Resilience Assessment Tool (Appendix S2)

Study site	Environment	Land management objective	Land management practices	Main land managers
Conservation logging (Por_1)	Sub-humid pine forest	Minimizing impact of logging operations on pine recruitment in burnt pine forests	Post-fire conservation logging	Company/ Government employees
Traditional logging (Por_2)	Sub-humid pine forest	Maximizing wood extraction in burnt pine forests	Post-fire traditional logging	Company/ Government employees
Restored shrubland (Spa_1)	Arid shrub-land	Restoring soil fertility and combating desertification in degraded shrubland	Plantation of semi-arid woody species with micro-catchments Plantation of diverse semi-arid woody species Plantation of semi-arid woody species on terraces	Company/ Government employees
Restored forest (Spa_2)	Semi-arid pine forest	Conserving landscape, preventing soil erosion and reducing fire risk in pine forest	Selective forest clearing Cleared strip network system (firebreaks) Afforestation with Pinus halepensis after fire	Small-scale land users
Diversified shrubland (Spa_3)	Semi-arid shrub-land	Increasing resilience to fire and biodiversity in shrubland	Clearing of fire-prone seeder species. Planting of resprouter shrubs and trees	Company/ Government employees
Seasonal pasture (Ita_1)	Humid grassland with shrubs	Regulating grazing and preventing damage from wild boars in pastures	Metallic fences to regulate grazing	Small-scale land users
Silvo-pastoral system (Gre_1)	Semi-arid shrubland	Restoring vegetation and diversifying income in shrub dominated pastures	Grazing land afforestation with carob trees	Small-scale land users
Extensive grazing (Cyp_1)	Arid Shrub-land	Reducing degradation from overgrazing in shrub dominated pasture	Planting carob and olive trees to prevent erosion	Small-scale land users

Table 3. Land management practices identified grouped by type.

Type of land management	Land management practice	Study site
Clearing of vegetation	Post-fire conservation logging	Por_1
	Post-fire traditional logging	Por_2
	Selective forest clearing	Spa_2
	Cleared strip network system (firebreaks)	Spa_2
	Clearing of fire-prone seeder species.	Spa_3
Grazing management	Metallic fences to regulate grazing	Ita_1
	Controlled grazing in spring months	Gre_1
Planting of shrubs	Plantation of semi-arid woody species with micro-catchments	Spa_1
	Spatially diverse plantation of diverse semi-arid woody species	Spa_1
	Plantation of semi-arid woody species on terraces	Spa_1
	Planting of resprouter shrubs and trees	Spa_3
Planting of trees	Afforestation with *Pinus halepensis* after fire	Spa_2
	Grazing land afforestation with carob trees	Gre_1
	Planting carob and olive trees to prevent erosion	Cyp_1
Other	Carob tree protection from rats	Cyp_1
	Fodder provision to animals during summer	Cyp_1

Table 4. Ecosystem services indicated as important by stakeholders for each study site (see Appendix S2, section 2). Selection of ecosystem services was based on a predefined list of services derived from the WOCAT method where “productive” refers mostly to provisioning services, “ecological” to regulating services, “sociocultural” to cultural services. However, stakeholders were asked to complete the list with those services they deemed important and which were not on the list. “X” indicates that no ecosystem services were identified as important in that category.

Study site identifier		Productive Services	Ecological services	Sociocultural services
Por_1	Conservation logging	Animal and plant productivity Water (quantity and quality) for human, animal, and plant consumption	Reduced erosion	Recreation (e.g. tourism, sports)
Por_2	Traditional logging	Animal and plant productivity	X	Cultural services (e.g. maintaining traditional landscape)
Spa_1	Restored shrubland	X	Reduced erosion Above ground biodiversity Protection from extreme events	Recreation (e.g. tourism, sports)
Spa_2	Restored forest	Animal and plant productivity	Reduced erosion Above ground biodiversity Greenhouse gas absorption Protection from extreme events	Recreation (e.g. tourism, sports)
Spa_3	Diversified shrubland	X	Greenhouse gas absorption Protection from extreme events	X
Ita_1	Seasonal pasture	Animal and plant productivity	X	Cultural services (e.g. maintaining traditional landscape)
Gre_1	Silvopastoral system	Animal and plant productivity Land available for production	Reduced erosion Above ground biodiversity	Cultural services (e.g. maintaining traditional landscape)
Cyp_1	Extensive grazing	Animal and plant productivity	Reduced erosion Above ground biodiversity Greenhouse gas absorption	X

Table 5. Impact of disturbances measured as the ratio between ecosystem services that can be decreased by a disturbance (derived from the RAT, section 4.1) and the number of ecosystem services identified as important (eq. 1), grouped by disturbance. Values close to 0 mean no permanent impact on important ecosystem services, while close to 1 means all important ecosystem services are affected. “n” represents the number of study sites affected by each disturbance (out of 8).

Disturbances	Mean impact	Standard deviation	n
Wildfires	0.74	0.23	6
Droughts	0.77	0.22	5
Pests/ Diseases	0.65	0.34	4
Torrential rainfalls	0.63	0.14	2
Floods	0.25	0.00	1

Table 6. Quantitative evaluation of the impact of each land management practice (LMP) to the resilience of the land management systems in relation to different disturbances, organized by study site. *Impact* refers to the impact of disturbances on the ecosystem services identified as important by stakeholders D_j (eq. 1) which ranges from 0 (no impact) to 1 (all important ecosystem services are affected). The direct influence of LMPs on the resilience of land management systems ($I_{i,j}$, eq. 2) is calculated considering prevention (p), mitigation (m), and recovery (v), and ranges from -6 to 6. $\boldsymbol{r_{i,j}}$ refers to the resistance of land management to disturbances; its values can be 0, 1, 2, or 3. *Resilience* refers to the overall impact of LMPs on resilience calculated using eq. 3 and can range from -1 to 1.

Land management practice		**Disturbance**		**Influence of LMP**				$\boldsymbol{r_{i,j}}$	**Resilience**
Study site	Land management practice	Name	Impact (D_j)	p	m	v	$I_{i,j}$		$R_{i,j}$
Por_1	Conservation logging	fires	0.75	-1	0	-1	-2	0	-0.25
	Conservation logging	pests / diseases	0.25	-1	1	0	0	0	0.00
Por_2	Traditional logging	fires	1.00	1	0	-1	0	0	0.00
	Traditional logging	pests / diseases	1.00	-1	2	0	1	0	0.17
Spa_1	Shrub plantation with catchments	droughts	1.00	0	1	1	2	3	-0.17
	Diverse shrub plantation			0	1	1	2	3	-0.17
	Shrub plantation with terraces			0	0	0	0	1	-0.17
	Shrub plantation with catchments	torrential rainfalls	0.75	0	2	1	3	2	0.13
	Diverse shrub plantation			0	2	1	3	1	0.25
	Shrub plantation with terraces			0	2	1	3	2	0.13
	Shrub plantation with catchments	floods	0.25	0	1	1	2	3	-0.04
	Diverse shrub plantation			0	2	1	3	3	0.00
	Shrub plantation with terraces			0	2	1	3	3	0.00
Spa_2	Selective clearing	fires	1.00	2	2	1	5	1	0.67
	Fuel breaks			2	2	0	4	2	0.33
	Afforestation with P. halepensis			-1	1	1	1	3	-0.33
	Selective clearing	droughts	0.67	0	1	1	2	0	0.22
	Fuel breaks			0	0	0	0	1	-0.11
	Afforestation			0	1	1	2	3	-0.11
Spa_3	Shrub clearing	fires	0.50	2	2	1	5	0	0.42
	Resprouter shrub plantation			0	1	2	3	1	0.17
	Shrub clearing	droughts	1.00	0	2	1	3	0	0.50
	Resprouter shrub plantation			0	0	0	0	2	-0.33
Ita_1	Fences	pests / diseases	1.00	1	1	1	3	1	0.33
Gre_1	Carob plantation	fires	0.80	0	0	2	2	1	0.13
	Controlled grazing			1	2	1	4	2	0.27
	Carob plantation	pests / diseases	0.50	1	1	1	3	2	0.08
	Controlled grazing			1	1	1	3	2	0.08
	Carob plantation	droughts	0.40	0	-1	1	0	2	-0.13
	Controlled grazing			0	-1	0	-1	1	-0.13
Cyp_1	Carob plantation	droughts	0.75	-1	1	1	1	1	0.00
	Tree protection			0	1	1	2	0	0.25
	Fodder provision		0.75	0	2	1	3	1	0.25
	Carob plantation	fires	0.50	-1	0	1	0	1	-0.08
	Tree protection			0	1	1	2	2	0.00
	Fodder provision			0	1	1	2	0	0.17
	Carob plantation	torrential rainfalls	0.50	0	1	1	2	0	0.17
	Tree protection			0	2	1	3	0	0.25
	Fodder provision			0	0	1	1	1	0.00

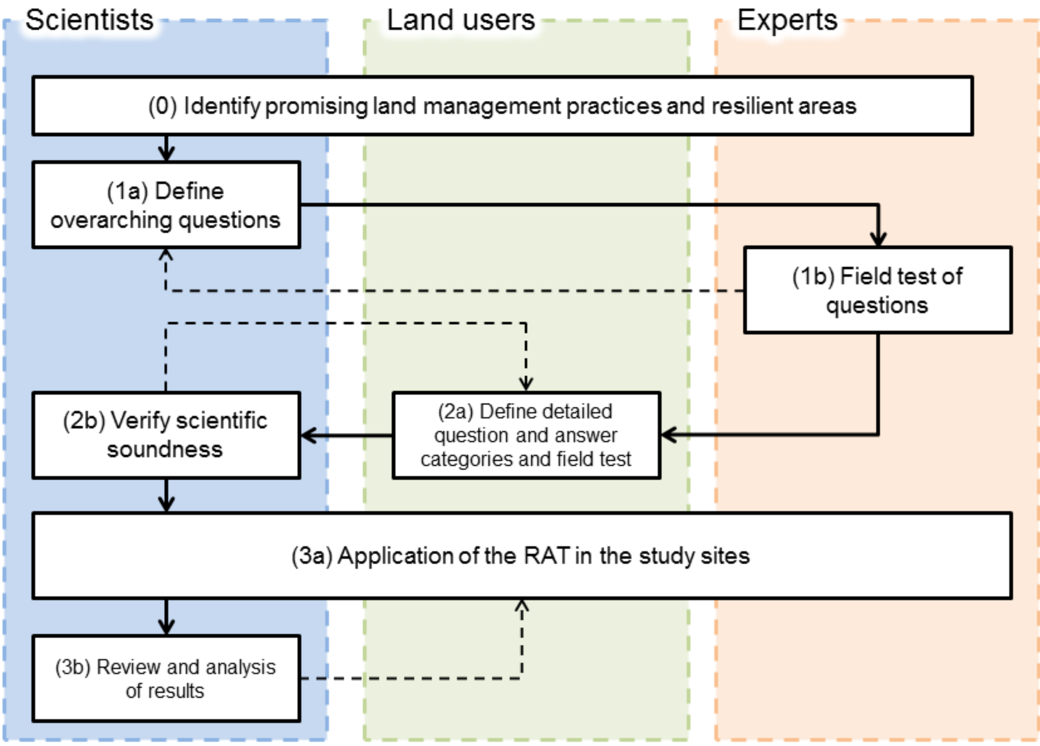

Figure 1. Design process of the Resilience Assessment Tool (RAT) and interactions with different stakeholder groups. “Experts” refers to local experts or land management advisors; “land users” includes land owners, shepherds, and forest workers. Dashed lines represent review after testing phases. Detailed description of each phase is presented in Method S1

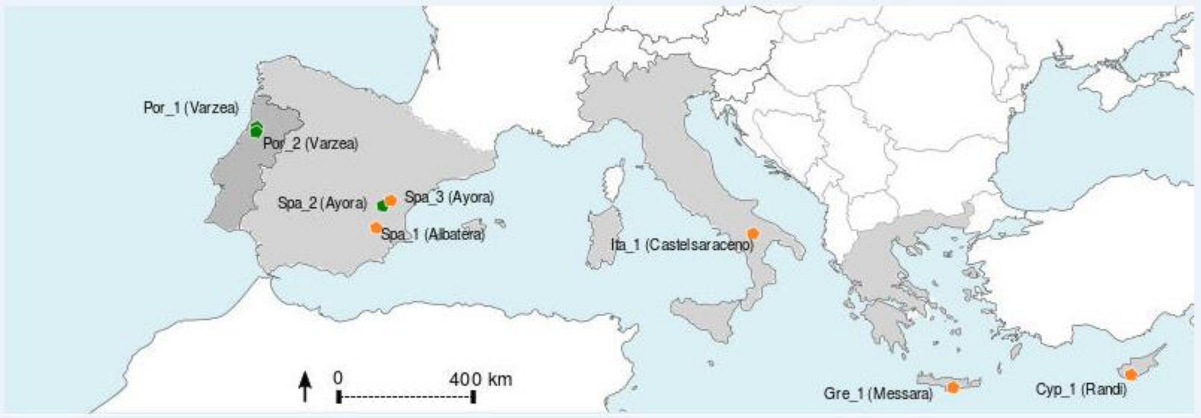

Figure 2. Location of study sites with place names in brackets. Study site countries are depicted in dark grey. Forest sites are marked in green, while rangeland sites are marked in orange.

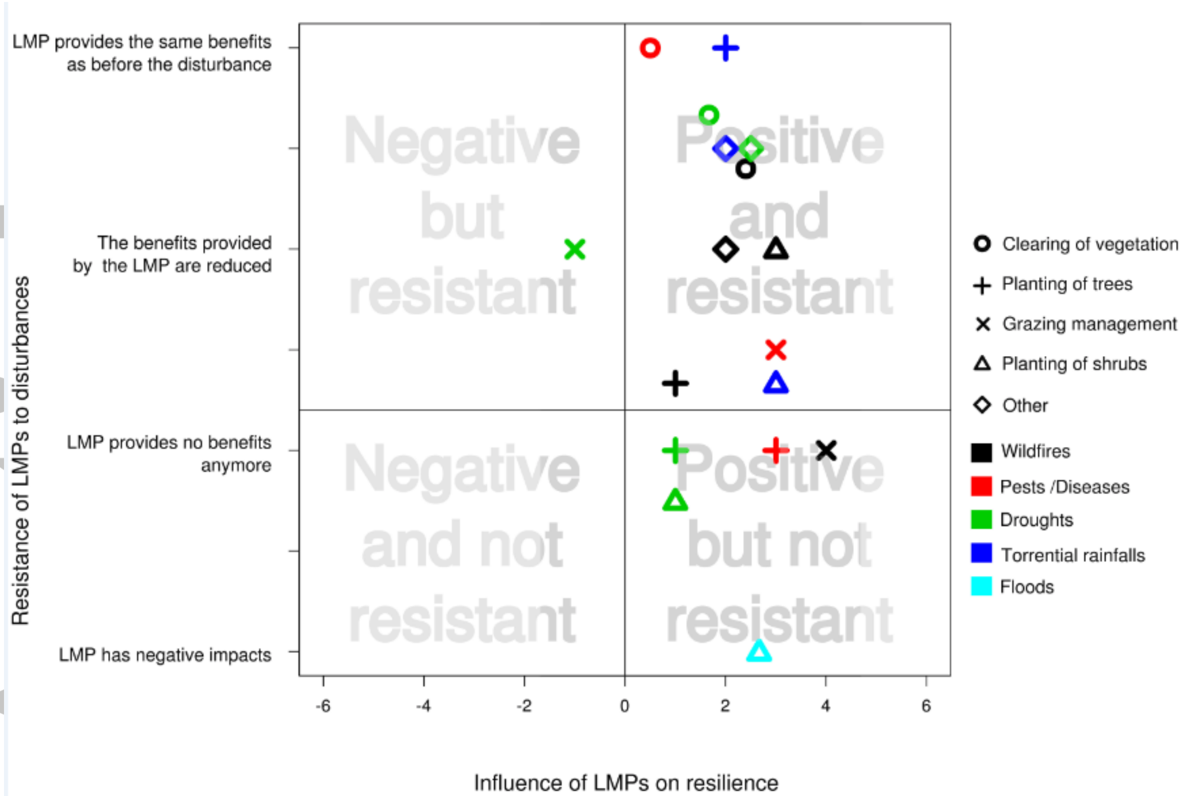

Figure 3. Average influence of land management practices (LMPs) on the disturbance (x axis; relative units) and resistance of LMPs to the disturbance (y axis) by type of practice. The shapes correspond to the different LMP types, the colour indicates the type of disturbance, and lines separate positive from negative evaluations.

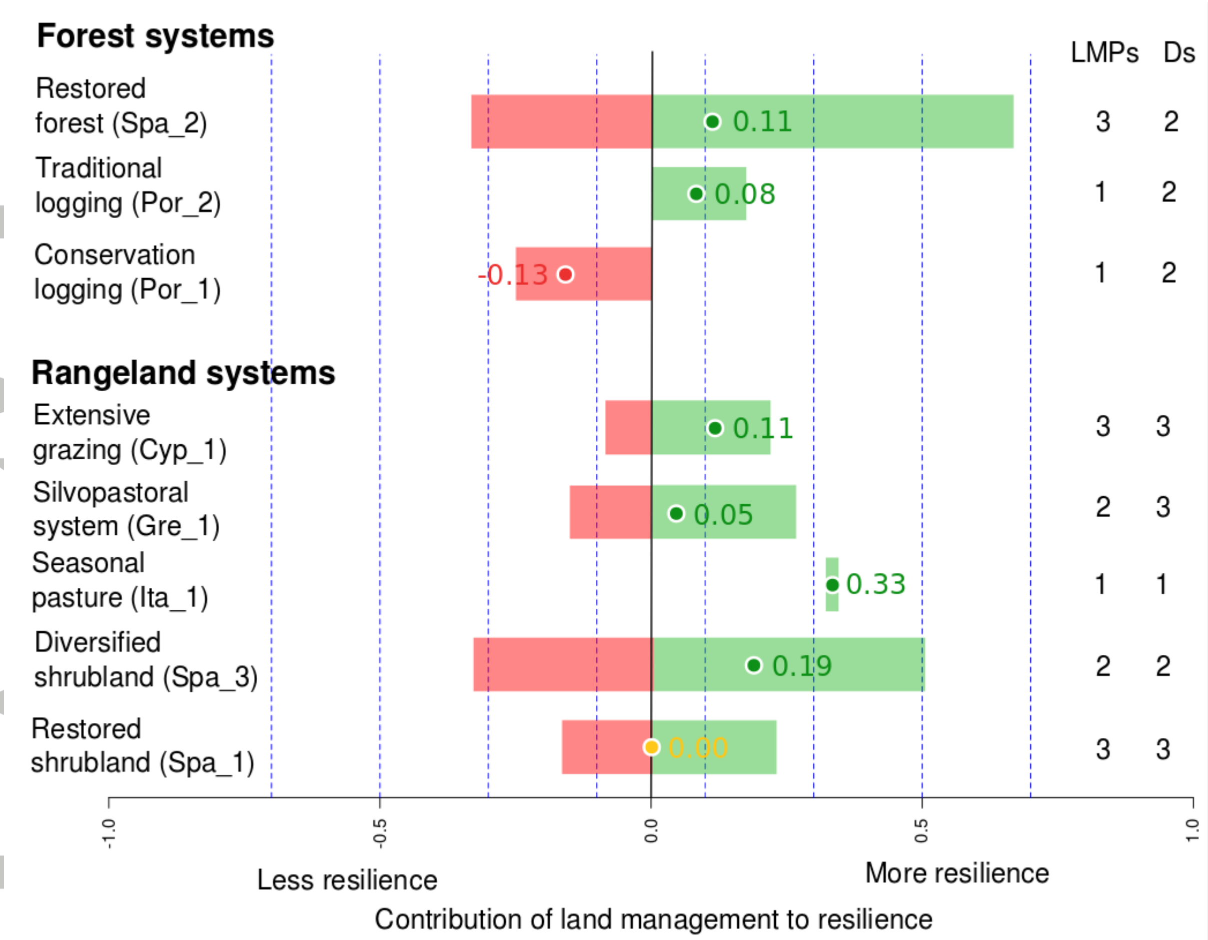

Figure 4. Contribution of land management practices (LMPs) to the resilience of each land management system. The bars range from minimum to maximum resilience values (considering all LMPs in relation to all the disturbances affecting each land management system); the dots indicate the average value. For each land management system, LMPs indicate the number of practices, and Ds indicate the number of different disturbances.